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Geology of the Elk Run Gas Pool, Jefferson County, Pennsylvania

Louis Heyman

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Geology of the Elk Run Gas Pool, Jefferson County, Pennsylvania

by Louis Heyman
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PREFACE

This study is an analysis and guide to the geology and reservoir behavior of a recently discovered gas pool in the Ridgeley Sandstone of Lower Devonian age.

The Elk Run pool is located on the southeast side of a major anticline in west-central Pennsylvania. The gas is trapped in the Ridgeley Sandstone between an updip porosity loss in the sandstone and the filling of the downdip pore space by water. It is typical of nearby gas pools in the same formation.

This study will be primarily of interest to those concerned with exploration for natural gas and evaluation of natural gas reserves. It demonstrates the type and quantity of data required, and how these data can be utilized in analyses of gas pools.

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GEOLOGY OF THE ELK RUN GAS POOL, JEFFERSON COUNTY, PENNSYLVANIA

By
Louis Heyman

ABSTRACT

The Elk Run gas pool is a stratigraphic trap typical of the northeast-southwest trending series of "Oriskany" gas pools on the east limb of the Sabinsville anticline in west-central Pennsylvania.

Entrapment is largely due to an updip porosity loss, which is about a mile downdip from a regional pinchout of the Ridgeley Sandstone of the Oriskany Group. Minor portions of the entrapment are due to a northeast-southwest trending, downthrown-to-the-south fault at the north end of the pool, and a southwest-plunging nose at the south end. Downdip entrapment is against the gas-water contact at minus 5,940 feet.

Porosity is largely intergranular, with a maximum of about 20 percent and a mean of 7.75 percent, increasing in quality and thickness downdip. The reservoir is considered to be localized by the distribution of Ridgeley Sandstone having greater than 6 percent porosity.

The original shut-in pressure was 3,960 psi, an overpressure of about 440 pounds for an average depth to the Ridgeley Sandstone of 7,246 feet. The original producible gas in place is estimated at 46,670,000 MCF, with a recovery factor of 809.7 MCF per acre-foot.

Similar analyses can be made of other gas pools in Pennsylvania. From these analyses, quantitative evaluation of these pools is possible.

INTRODUCTION

ACKNOWLEDGEMENTS

The Pennsylvania Geological Survey appreciates the help furnished by many organizations and individuals; particular thanks are due to Mr. Clifton Heathcote of Consolidated Gas Supply Corporation, Clarksburg, West Virginia, and Mr. J. J. Oberle of Schlumberger Well Surveying Corporation, Allison Park, Pennsylvania. The aid of W. S. Lytle in gathering and interpreting production data and the constructive criticisms of D. R. Kelley and W. R. Wagner were invaluable.

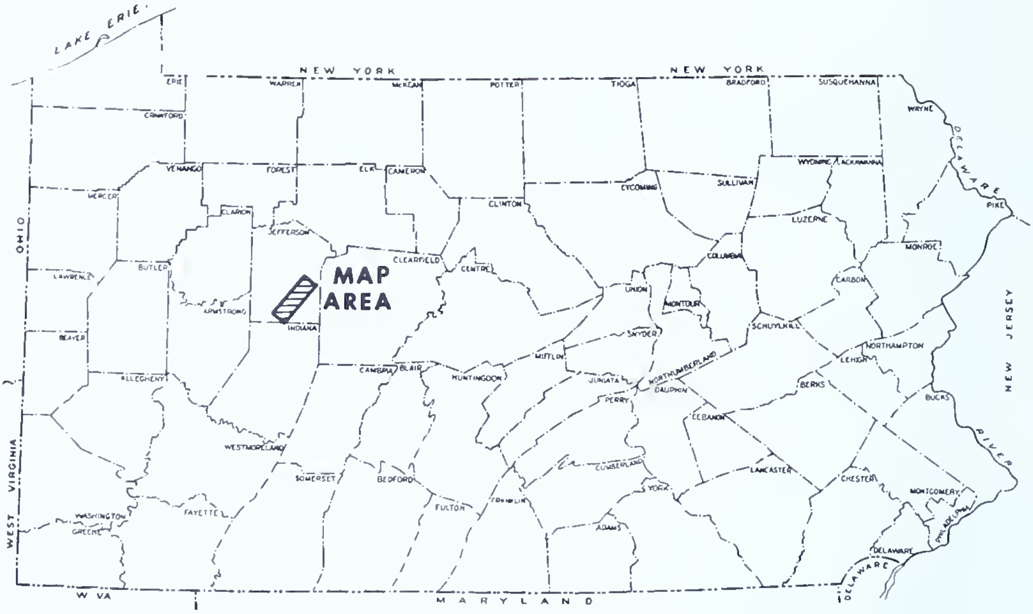


Figure 1. State map of Pennsylvania showing the location of the Elk Run gas pool.

GENERAL STATEMENT

Elk Run is the most southwesterly of the great series of Onondaga-"Oriskany" gas pools located on the east limb of the Sabinsville anticline in west-central Pennsylvania. This pool is of more than ordinary interest because it is one of the few "Oriskany" pools in which geophysical well logs were routinely run and made available to the Survey. This study was initiated in order to take advantage of this data and to give a more detailed and accurate picture of the reservoir than was possible in earlier developed pools in this area. Well completion and production data, correlated with these logs, made possible some general predictions of reservoir performance.

LOCATION

The Elk Run pool is located mainly in Perry and Young Townships, with one well each in Bell and McCalmont Townships, all in southeastern Jefferson County, Pennsylvania, directly west of Punxsutawney; and is located in section C of the Smicksburg and section A of the Punxsutawney 15-minute quadrangle maps (Figure 1).

METHODS OF INVESTIGATION

This study is based on geophysical well logs, completion data from Petroleum Information, Inc., drillers' logs, and production data from operators in the pool. The only well samples of the Onondaga to Helderberg interval available, from the Sam Jack 1 Bobal well (Dubois H 21), were examined to determine the lithologies in this section. The geophysical logs were correlated with the generally accepted subsurface stratigraphy in the area and with each other. No attempt was made to establish the general validity of this stratigraphy either regionally or in relationship to the outcrop sections.

Calculations of various parameters from the geophysical logs were performed by standard log analysis techniques (Schlumberger, 1962) and in general are regarded as examples of the uses of coordinated log, completion, and early-stage production data in the development of a gas pool.

HISTORY OF DEVELOPMENT AND COMPLETION METHODS

The pool discovery well, Consolidated Gas Supply Corporation 2 Rochester and Pittsburgh Coal N-982, (Punxsutawney A 41) Young Township, Jefferson County, a 7,198 foot Helderberg wildcat, was completed June 20, 1965, with an initial potential of 2,214 MCFGPD and a 199 hour shut-in pressure of 3,960 psi from open hole in Onondaga chert and "Oriskany" sandstone. There were 5 additional completions in 1965, 26 completions in 1966, 12 completions in 1967, and 3 dry holes, through August 31, 1967, the cut-off date for this report. Drilling was essentially complete at that time; only a few in-fill wells were subsequently drilled.

Development was at first southwest along strike from the discovery well (Punxsutawney A 41). The successful completion of the J & J Enterprises 1 Sutter (Smicksburg C 5) as a 2-mile southwest stepout from production opened the south end of the pool, and subsequent development trended northeast from there to meet the development coming southwest.

The wells were all rotary air-drilled and completed in the open hole, except for one early well in which casing was set through the pay and perforated. In some wells, gamma-ray temperature logs were run to just below the top of the Onondaga chert, casing set and cemented, and the holes then drilled to total depth into the top of the Helderberg Group. The majority were drilled into the Helderberg, with gamma-ray, density, and induction logs run to total depth and casing run and cemented just in the top of the chert. In one well, a sonic amplitude log was run through the pay zone.

Of the 44 completions and 3 dry holes, 16 were hydraulically fractured; most of these during the later stages of field development. The average potential of these 16 wells before fracture was 1,702 MCFGPD, and the average after fracture was 7,860 MCFGPD, an increase of 4.62 times. The smallest increase ratio was 1.10; the greatest was from "a show of gas" estimated at 10 MCFGPD to 5,126 MCFGPD, a ratio of 513. The largest potential after fracture was 20,731 MCFGPD.

The remainder of the producing wells were natural completions. The average initial potential was 4,729 MCFGPD, not including the prefracture potential of the treated wells. The highest natural initial potential was 13,385 MCFGPD. If these wells had been fractured on completion, assuming the same increase ratio of 4.62, their average potential after fracture would have been 21,848 MCFGPD.

STRATIGRAPHY

GENERAL STATEMENT

The strata discussed in this report are all included in the Ulsterian (Lower Devonian) Series, and a tripartite subdivision which superficially resembles the standard Ulsterian section can easily be made. Rigorous long-range correlations with the standard sections are beyond the scope of this report, thus these subdivisions are not claimed to be time-equivalents of the Onesquethaw, Deer Park, and Helderberg Stages, although the latter name is used in this paper.

SUBSURFACE

In the report area, the common subsurface practice is to divide this part of the rock column, that is the Lower Devonian, into three rock units. From the top down, they are as follows:

1. *Onondaga Formation* immediately underlies a conspicuous highly radioactive shale marker correlated with the Tioga Metabentonite, and overlies the "Oriskany" Sandstone. The Onondaga includes an upper, roughly 20 foot thick, pyritic, calcareous, dark-gray shale containing local stringers of limestone, and a lower, slightly silty and locally shaly chert which becomes more shaly in the lower 20 feet and is about 85 feet thick. The overall thickness of the Onondaga is thus about 105 feet in this area.
2. *"Oriskany" Sandstone* underlies the Onondaga Formation and overlies the Helderberg Group. The "Oriskany" is a very fine to medium, sporadically coarse grained, calcareous, poorly sorted, quartzose sandstone composed mainly of sub-rounded, frosted grains. It pinches out updip approximately 1 to 2 miles northwest of the Elk Run pool, and is 24 to 26 feet thick at the downdip

(southeast) margin of the pool. Based on density log data, most porous zones are in the upper two-thirds of the unit, and decrease in quantity downward. Commonly the uppermost foot or two of the unit is a hard, tight streak.

3. *Helderberg Group,* underlying the "Oriskany", was penetrated to 44 feet below the base of the "Oriskany" in the J & J 2 Meneely (Smicksburg C 13) in the field, and 96 feet below the "Oriskany" in the NYSNG 1 R & P Coal N947 (Dubois H 40), a nearby dry hole. It is generally a gray to brownish-gray, dense, cherty, impure limestone, and from the gamma-ray log of the 1 R & P Coal, appears to become more argillaceous downward. No pre-Helderberg rocks were reported.

Departing somewhat from the conventional nomenclature given above, the "Oriskany" Sandstone will henceforth be called Ridgeley in this report. In the standard section of Pennsylvania, the Oriskany is a group composed of the Ridgeley Sandstone above and the Shriver Chert below. The use of the name "Oriskany" thus implies that the lower part of the sandstone is equivalent to the Shriver Chert. There is no evidence for this, and the Shriver Chert, if present, may actually be included in the Helderberg of the subsurface. The name Helderberg will be used without quotation marks, since the presence or absence of the Shriver Chert in this area was not ascertained.

STRUCTURE

REGIONAL SETTING

Elk Run is the most recently discovered and most southwesterly of a group of four pools located on a northeast-southwest trend on the southeast flank of the Sabinsville anticline. The anticline is a major structural feature extending southwest about 115 miles from northwest Tioga County near the New York state line, to southeastern Jefferson County. From northeast to southwest, these pools are Whippoorwill, Boone Mountain, DuBois, and Elk Run, extending 56 miles overall along strike (Cate, 1962). The pools are not identical, however, since fault closure, as an essential part of the trap, and the presence or absence of fracture porosity in the reservoir vary widely among them.

LOCAL STRUCTURE

The major structural feature in the Elk Run area is the nose at the southwest end of the pool. (See structure maps and structure section A-A′, Plate 2.) This nose is a generally southwest plunging feature with 250 feet of relief where it is best developed. It can be considered a minor interruption of the east limb of the Sabinsville anticline, which otherwise dips without interruption into the Punxsutawney syncline. (Compare with Figure 2.)

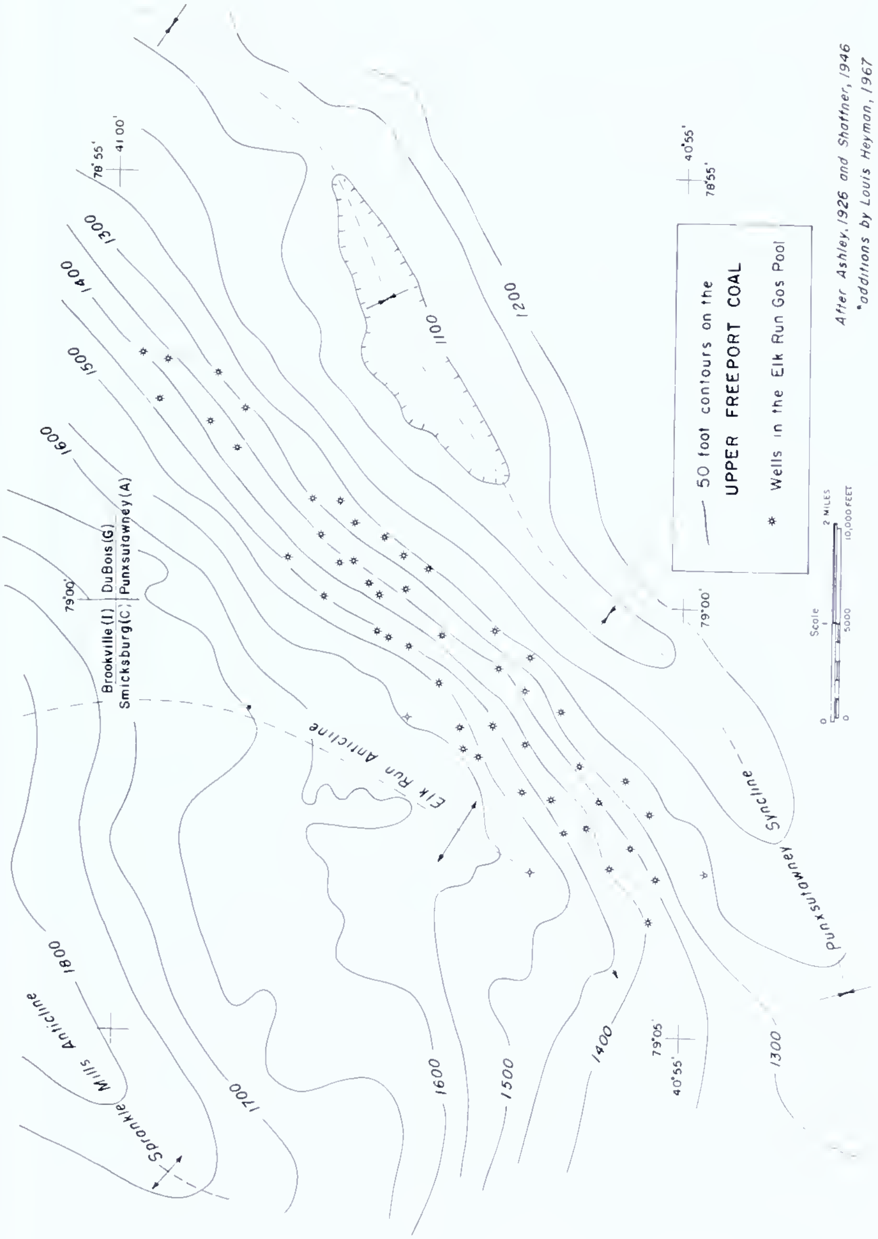
At the northeast end, the pool is probably closed by a northeast-southwest trending fault, downthrown to the south, with 350 feet of throw as contoured on the base of the Ridgeley Sandstone. The fault was inferred from a difference in elevation at the top of the Ridgeley Sandstone of 645 feet in 7,600 feet horizontally, that is 1 foot in 11.8 feet (40°) between wells Dubois H 21 and H 41. The alternative to a fault would have been to contour this locality at a dip almost twice that of the area average (1 foot in 20, 26°) and greater, by a small margin, than the steepest dip in the pool (1 foot in 12.6, 38°) between wells Smicksburg C 5 and C 20. Faulting has been found in this vicinity by seismic survey, according to one operator in the pool.

The shallow structure is broader and gentler than the deep structure, with the Elk Run anticline expressed only as a weak irregular bulge in the contours on the Upper Freeport coal (Ashley, 1926; Shaffner, 1946; Figure 2, this paper). The coincidence between deep structure mapped on the Onondaga or Ridgeley and surface structure mapped on the Upper Freeport coal (Ashley, 1926; Shaffner, 1946) indicates that major deformation was at least post-Upper Freeport coal, that is, post-Middle Pennsylvanian. The theory of Appalachian structure put forth by Gwinn (1964) which postulates convergent folds with limbs thrust faulted at depth is sufficient to explain the present Elk Run structure and its neighbors.

CONTROL OF RIDGELEY SANDSTONE DISTRIBUTION

In order not to complicate the following highly hypothetical discussion, it is assumed there was no truncation of a uniformly deposited Ridgeley Sandstone to cause present sandstone distribution. Two depositional hypotheses are offered to explain the present sandstone distribution. The first is that draping and accompanying non-deposition of post-Helderberg beds on pre-existing local seabottom highs, whether structurally or otherwise formed, would serve to explain the absence of the Ridgeley west of Elk Run. Alternatively, a regional facies change to the west of the Ridgeley into non-clastics or shale, and the consequent lumping of this facies either into the Onondaga above or the Helderberg below, would account for the disappearance of the sand.

The local control hypothesis emphasizes a picture of irregular sand distribution; the regional facies change hypothesis implies the picture on Jones' and Cate's 1957 map and on Cate's 1962 map, of a large regional "no-sand" area. Obviously the former hypothesis is more encouraging to wildcatting in this area than the latter.



After Ashley, 1926 and Shaffner, 1946
**additions by Louis Heyman, 1967*

Figure 2. Structure map of the Elk Run gas pool with base on the Pennsylvanian Upper Freeport coal.

In support of the first idea, the Mays gas pool, which produces from the Ridgeley Sandstone, is located in Clarion quadrangle, Clarion County, in the very heart of the "no-sand" area. Further, if most of the tests drilled in the "no-sand" area were originally located on "highs" of some kind, they would have been predestined to miss the sand and end as dry holes.

In support of the second hypothesis, the postulated facies change could be to carbonate rocks, presumably now regarded as part of the Onondaga or the Helderberg, and the searcher would have to carefully examine those parts of the section in the various "no-sand" area wells to detect Ridgeley equivalents which might be potential reservoirs.

There is at present no well data near Elk Run to give much support to either of the hypotheses, and further discussion of this problem is beyond the scope of this study.

ELK RUN RIDGELEY SANDSTONE RESERVOIR

GENERAL STATEMENT

The Ridgeley Sandstone is herein considered the major reservoir in the Elk Run pool for the following reasons:

1. The zero thickness contour of Ridgeley Sandstone with over 6 percent porosity also marks the updip edge of the pool as delineated by producing well locations. Two tests (Smicksburg C 25 and C 28) located beyond this boundary were dry holes, although completion from the Onondaga chert as well as the Ridgeley Sandstone was attempted. (See Plate 1, Figure 5.)
2. A sonic amplitude log was run in one well, Consolidated Gas Supply 1 Straitiff N-1019, (Punxsutawney A 49). This log shows 9 feet of fracture porosity near the top of the 83 foot thick Onondaga chert, whereas the same log shows 14 feet of fracture porosity in the 24 foot thick Ridgeley Sandstone.

   The formation density log on the same well shows an 8-foot streak of dubious porosity in the chert, whereas this same log shows 6 feet of over 6 percent interstitial porosity and 7 feet of between 3 percent and 6 percent interstitial porosity in the Ridgeley Sandstone. This zone of interstitial porosity in the Ridgeley covers about the same interval as the fracture porosity. Based on this log and the general similarity of the other density logs to this one, it is reasonable to infer that most of the reservoir capacity at Elk Run is in the sandstone.
3. In those cases where the drillers' logs reported gas shows in the wells, every reported first show of gas was in the Ridgeley, not in the overlying Onondaga chert.

AREA AND VOLUME OF RESERVOIR

The Ridgeley Sandstone reservoir is considered to be that area enclosed on the northwest by the zero thickness contour of Ridgeley Sandstone with over 6 percent porosity, on the northwest by a northeast-southwest trending fault downthrown to the south, and on the south and southeast by the gas-water contact at minus 5,940. (See Plate 1, Figure 5.)

The pool is not delineated by dry holes except on the extreme southeast and on the southern end of the northwest flank (Plate 1, Figure 3). The gas-water contact was calculated from the electric logs of the Smicksburg C 5 and C 21 wells, assumed from the log relationships to be essentially horizontal, and extrapolated on strike to give a logical boundary for the downdip side of the field (see below).

The area of the reservoir enclosed by the above boundaries is 6,318 ± 5 acres (one standard deviation) by planimeter measurement. The locale of fracture porosity is surmised to be similar in extent and position based on the data from well Punxsutawney A 49 and production data.

The total volume of the reservoir, that is, the net pay volume, is considered as essentially the volume of Ridgeley Sandstone with greater than 6 percent interstitial porosity. The reason for this limit is discussed later under "Porosity and Water Saturation". This volume is 57,642 ± 43 acre-feet (one standard deviation), calculated by planimetering the area within each thickness contour except the zero contour, multiplying the area by the contour interval (here 2 feet), and adding the results. The average pay thickness of 9.123 feet of sandstone with over 6 percent porosity was found by dividing the net pay volume by the area of the reservoir.

SAND THICKNESS

The Ridgeley Sandstone wedges out northwest of the Elk Run pool, on the southeast side of the so-called "no-sand" area (Cate, 1962; Jones and Cate, 1957). This pinchout is about a mile updip from the zero thickness contour of porous sandstone as defined below. Conversely the sand thickens downdip, southeast, to a maximum of 24 feet in the pool vicinity (Plate 1, Figure 4).

This geometry is normal for the region, except that the rate of thickening is much greater than predicted on Jones' and Cate's (1957) isopach map of the Ridgeley Sandstone. The maximum thickness in the area appears to be about 30 feet, to the south in Indiana County.

POROSITY AND WATER SATURATION

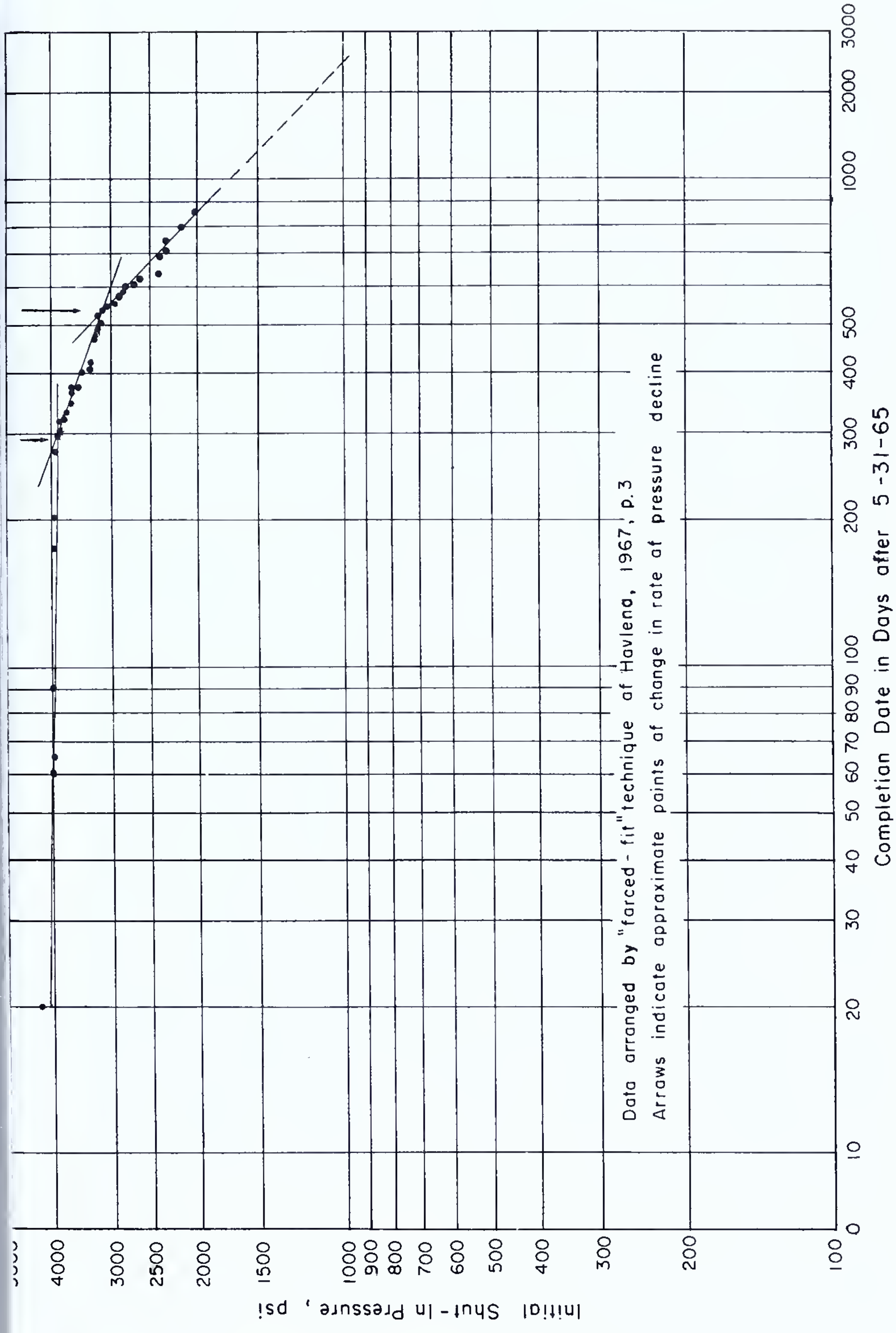
Porosity in the Ridgeley Sandstone is both interstitial and fracture; unfortunately there is insufficient data to accurately determine the quality or distribution of the fracture porosity.

Fracturing is definitely present in the Ridgeley Sandstone in at least one well, the Consolidated Gas Supply 1 Straitiff N-1019 (Punxsutawney A 49), as shown by the sonic amplitude log of that well. The fracture porosity is essentially vertically coextensive with the interstitial porosity in this well. Although there is 14 feet of fracture porosity in this well, the natural IP was only 3,714 MCF, and even after hydraulic fracture, improved only to 4,632 MCF. The implication is clear that fracture porosity, although present, is poorly developed and not extensive in the vicinity of this well.

The existence of a limited fracture network throughout the Ridgeley reservoir is suspected from the behavior of well shut-in pressures and from the distribution of natural initial potentials. The initial shut-in pressures of the wells were related to completion date even when the wells were remote from one another, thus indicating free communication between wells (Figure 3). This agrees with data from other pools along this trend.

A preliminary draft of natural initial potentials spotted on a net-pay map showed no apparent relation to the net-pay thickness except at the northwest margin of the pool, where the net pay thins to zero. In general, natural IP's over 5,000 MCFGPD were irregularly distributed in line northeast-southwest down the central part of the pool from the Punxsutawney A 43 at the northeast through Punxsutawney A 41 and the Smicksburg C 6 to the Smicksburg C 15 at the southwest end of the pool, with initial potentials decreasing out toward the margins of the pool both northwest and southeast of this line. In addition, the three largest wells in the pool (Punxsutawney A 46, IP 13,385 MCF, Smicksburg C 6, IP 11,300 MCF and Punxsutawney A 55, IP 8,800 MCF) were in no case offset by a well that had an IP within 1,000 MCF of their potential. The closest relationship was that of the Punxsutawney A 55, offset 1,850 feet to the west by Punxsutawney A 48 with an IP of 7,583 MCF, but which was also offset only 1,550 feet north by the Punxsutawney A 51 with an IP of 2,494 MCF.

It is my feeling that this weakly ordered pattern of IP distribution is due to the fracture network also implied by the shut-in pressure history. If the fracture pattern were better developed and more extensive, the potentials would be more uniform and more closely related to completion date, as is the shut-in pressure, whereas if there were little or no fracturing in the reservoir, the IP's would be a function of net-pay thickness per well, which is not the case.



Data arranged by "forced-fit" technique of Havlena, 1967, p.3

Arrows indicate approximate points of change in rate of pressure decline

Figure 3. Graph showing the initial shut-in pressures versus the completion dates of wells in the Elk Run gas pool.

Fracture porosity, where present, may add to the overall quality of the Ridgeley reservoir, but does not form the major part. It forms the reservoir in the Onondaga Chert in many nearby "Oriskany" pools, but is distinctly subordinate at Elk Run.

In the Ridgeley generally, interstitial porosity is concluded to be a function of intergranular cementation, rather than of the amount of clay-size material present, since an examination of the only available cuttings from the Ridgeley, from the Dubois H 21 well, showed little or no clay. Loss of pore space by precipitation of calcareous or siliceous cement around the grains or by pressure-welding of quartz grains is of major importance, and is a regional phenomenon.

Good density log control gives calculated interstitial porosities dominantly in the range 3 to 10½ percent, with a few values as low as 1½ percent and one value of 21 percent. The mean of 85 calculated porosities from the logs of 7 wells (Smicksburg C 5, C 22, C 24, C 29; Punxsutawney A 54, A 57, A 60) is 7.75 percent (See Figure 4).*

Interstitial porosity distribution is in the form of a wedge with the narrow edge northwestward, and thickening downdip to the southeast, subparallel to the sandstone distribution.

The porosity map (Plate 1, Figure 5) shows, in addition to the thickness of sand with over 6 percent porosity, the number of feet of sand with 3 to 6 percent porosity. The obvious conclusion to be drawn from this map and the stratigraphic section is that the porous zone both thickens and increases in quality downdip. The increase in thickness of the porous interval is limited by the maximum sand thickness, until in many cases the entire sand interval is porous to some extent in downdip wells (Plate 2). This is demonstrated by the difference between updip well Punxsutawney A 49, which has a total of only 13 porous feet out of 24 feet of sandstone, whereas all 23 feet of sandstone in downdip well Punxsutawney A 57 are porous to some extent. In addition, well A 49 has only 6 feet of sand with over 6 percent porosity, whereas well A 57 has 19 feet with over 6 percent porosity.

A semi-log plot of percent water saturation versus percent porosity was made from data calculated from density and induction logs of seven wells on the downdip side of the pool (Figure 4). It is generally accepted (Levorsen, 1967, p. 147, 153, 160) that a reasonable maximum for a commercially productive gas reservoir is 40 percent interstitial water saturation. This is found on Figure 3 to correspond to 3 percent porosity; correcting for water saturation gives a net effective porosity of 1.8 percent. At 6 percent porosity, the interstitial water saturation is 24 percent, giving

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* Grain density used in calculations of porosity is from values for fragments of "Oriskany Sand" from the Kanawha-Jackson field, West Virginia, reported in Headlee and Joseph (1945).

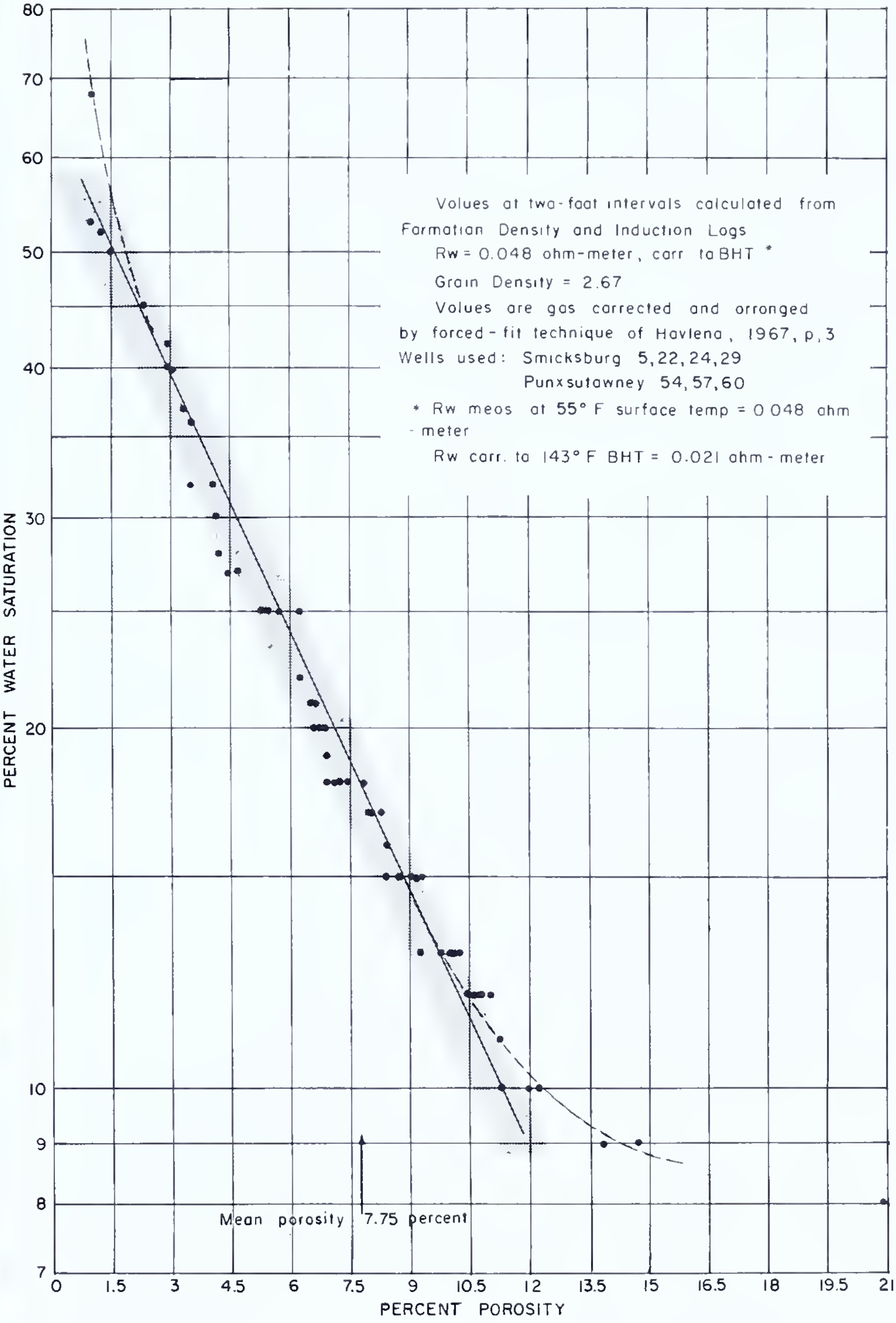

Figure 4. Graph showing the calculated interstitial water saturation versus the calculated interstitial porosity of the Ridgeley Sandstone reservoir in the Elk Run gas pool.

a net effective porosity of 4.6 percent. The maximum thickness of sandstone with porosity between 3 and 6 percent was found to be 8 feet in well Smicksburg C25 and 15 feet in well Dubois G 42. Both had negligible sandstone with over 6 percent porosity, produced little fluid of any kind, and were abandoned as dry holes. It is therefore concluded that the critical quantity, the value governing the quality of a well in this pool, is the number of feet of Ridgeley Sandstone with over 6 percent interstitial porosity.

GAS-WATER CONTACT

The gas-water contact in the reservoir was calculated on the basis of the value of R_t (true formation resistivity) for 3 percent porosity and 80 percent interstitial water content. This value for water saturation is double the previously cited commercial maximum and thus assuredly indicates production of 100 percent water. R_t/R_w corresponding to these values was found to be 1,800 from Schlumberger Chart D-26, (Schlumberger, 1962) and calculating on the basis of R_w (resistivity of formation water) equals 0.021 ohm-meter at bottom hole temperature, R_t equals 38 ohm-meters.* This value was found on the induction logs at 7,134 (—5,941) in well Smicksburg C 5 and 7,168 feet (—5,953) in well Smicksburg F 21. The datum minus 5,940 was therefore chosen as the gas-water contact, and is considered the downdip pool limit.

RESERVOIR PRESSURE AND SIGNIFICANCE

The completion shut-in pressure of the discovery well (Punxsutawney A 41) was 3,960 psi after 199 hours shut-in, and is believed to be approximately the virgin reservoir pressure. The average depth to the top of the Ridgeley Sandstone is 7,246 feet, while the average wellhead elevation is 1,420 feet.

The lowest local elevation is 1,200 feet, at the southwest end of the pool, thus the average local relief is 220 feet. Assuming the rocks carry fresh water to 300 feet below the surface at the lowest point gives a total fresh water column of 520 feet at an average well location. The remainder of the water column to the top of the Ridgeley is assumed to be saline, with a head of 0.4897 psi/foot (see footnote). Average hydrostatic pressure at the top of the Ridgeley in the pool area should therefore be 520 x 0.433 psi/foot (fresh water column), plus 6,726 x 0.4897 psi/foot (saline water column), equals a pressure of 3,519 psi at a depth of 7,246 feet.

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* R_w and hydrostatic gradient used in calculations of water saturation and theoretical reservoir pressure respectively, are from data on an "Oriskany" water sample from Manufacturers Light and Heat 1 Green Glen, (Penfield C 90), Punxsutawney-Driftwood field, Clearfield County, Pennsylvania. Data furnished by D.R. Kelley citing an analysis by USGS from sample caught at 7,370 feet, and received by the USGS January 9, 1959.

There is thus at Elk Run an excess over hydrostatic pressure of 441 psi. The additional length of fresh water column needed to furnish this excess is 1,018 feet. Therefore the theoretical elevation of a wellhead at the average well would need to be 2,438 feet above sea level.

Excess reservoir pressure is a phenomenon common to the entire group of "Oriskany" fields in west-central Pennsylvania; Elk Run is thus not unique and the abnormality increases to the northeast in this region (W. S. Lytle, personal communication). Excess reservoir pressure here commonly is thought to be related to regional post-gas emplacement tectonics and related loss of porosity in the reservoir rock due to intergranular cementation and pressure-welding of the quartz grains in the Ridgeley.

This tectonic explanation assumes that porosity loss by such a mechanism would advance as a front, crowd the gas into a smaller volume, and thereby raise the reservoir pressure. In a structural trap, this type of front advance would more likely shift the position of the gas pool by displacing the gas-water contact on the opposite side of the pool. In an updip porosity pinchout such as Elk Run, the advancing front might work as postulated, but only if the porosity loss advanced updip from the downdip side of the pool.

It seems to me more likely that porosity destruction due to either pressure-welding of quartz grains or introduction of cementing material (silica or carbonate) might be randomly distributed, with location of porosity loss controlled by grain to grain relationships, localized pressure-temperature-saturation of carbonate and silica conditions of the interstitial waters, or both. The eventual result would be interruption of the communicating pore-spaces forming the reservoir, and the breaking up of the pool into a series of small poorly interconnected gas pockets, thus decreasing the permeability of the reservoir. A later effect might be to force each of these minor gas bubbles to shift locally, before any change in volume and pressure occurred. When these local bubbles were finally completely cut off, the end result would be to increase the pressure in individual bubbles simultaneously with increasing isolation of the bubbles from each other. Finally, the reservoir rock would contain the gas as disseminated, non-communicating, high-pressure bubbles, not really a pool in the strict sense. The tectonic hypothesis is therefore rejected as inadequate.

A detailed study of fluid behavior in the subsurface Ridgeley Sandstone is needed for a solution to this problem and the related one of gas emplacement. Other factors besides fluid behavior may be important in creating the overpressure.

If we consider that the generally accepted load pressure exerted by a column of average sedimentary rock is about 1 psi per foot of height (actually 0.99 psi) (Levorsen, 1967, p. 402) it is obvious that we have here a source of enormous pressure, if any of it can be communicated to the reservoir fluids. In old, well consolidated rocks like those composing the lithologic column in central Pennsylvania, lithostatic pressure is probably almost completely transmitted by intergranular contact, consequently only a little of this overburden pressure is communicated to the associated fluids.

The generally recognized mechanism of transmission of overburden pressure to the fluid is compaction of the rock and consequent squeezing out of interstitial fluid, thus transferring the pressure generated to the fluid column and thus eventually to the gas. The rocks in the Elk Run lithologic column considered most likely to have residual capacity for compaction are the shales. The excess pressure at Elk Run has been calculated at 441 psi, and a shale count from the gamma-ray log of a typical Elk Run well, the Lee Minter 1 Younts (Punxsutawney A 48) shows 4,380 feet of shale in the section below 100 feet, the top of the log. Dividing the excess pressure by the number of feet of shale gives an increment of 0.101 psi per foot, or 10.2 percent of the lithostatic pressure. The depth-dependence of compaction makes the above calculation merely an approximation, but it can be considered an average increment which is probably smaller in the upper zones and greater in the lower.

The pressure decline curve (see Figure 3) shows two marked increases in slope. The first point is presumably related to the beginning of intensive development in the pool and the second to the beginning of large-scale gas withdrawals.

RESERVE ESTIMATES

It is emphasized at the outset that the following reserve figures, both for the pool as a whole, and per unit volume, are meant to be indicators of comparative size, not absolute values on which economic studies can be based.

In a 181-day period 7,923,000 MCF of gas was produced from Elk Run (personal communication, Robert E. Bayles, Consolidated Gas Supply Corporation), with an accompanying pressure drop of 675 psi, interpolated from Figure 3. Making no correction for departure from the Ideal Gas Law or for surface and reservoir temperature differences, the production per pound of pressure drop was 11,740 MCF. The original shut-in pressure was 3,960 psi gauge, and assuming an abandonment pressure of 0 psi at the surface, the total pressure decline will be 3,975 psi absolute. The original volume of recoverable gas in place in the reservoir therefore was 46,670,000 MCF at surface conditions. The data used are from the early production history of Elk Run; thus this reserve estimate is probably low.

Assigning all of this gas to the volume of the reservoir with over 6 percent porosity, that is 57,642 acre feet, gives 809.7 MCF per acre foot recoverable gas for the Ridgeley Sandstone reservoir in this pool.

The value used in the text, 809.7 MCF per acre foot, is higher than ordinarily encountered in poorly porous sands. Calculations from data given in the text for the Ridgeley Sandstone reservoir at Elk Run were made as follows: Using original shut-in pressure 3,960 psi or 269.4 atmospheres; calculated average porosity 7.75 percent; calculated water saturation at this porosity 18 percent, or 82 percent of the porosity water free; and 43,560 cubic feet per acre foot; gives 0.0775 x 0.82 x 43,560 x 269.4 = 746 MCF per acre foot.

My conclusions are that the surprising capacity of the Ridgeley Sandstone at Elk Run is due to its low water saturation, and that only about 64 MCF reserves per acre foot of reservoir are derived from fractures.

Since there are 6,318 acres within the pool limits and 44 completed wells to August 31, 1967, the average area per well is 143.6 acres. As can be seen from the maps, this is a deceptive value, due to the irregular well distribution in the pool. Using this spacing and the average net-pay thickness of 9.123 feet gives 1,310 acre feet of net pay per well. At 809.7 MCF per acre foot, the average reserves per well are 1,061,000 MCF.

CONCLUSIONS

Elk Run is similar to the other pools to the northeast along the strike of the regional Ridgeley Sandstone pinchout in west-central Pennsylvania, and also to the pools composing the giant Jackson-Kanawha field in western West Virginia (McClain, 1949). What is distinctive is that due in large part to the availability of geophysical logs of most of the wells in the pool, quantitative evaluations could be made early in the production history of the pool.

Similar studies can be made of gas reservoirs in any part of the section, and are especially valuable in delineating the area of potential production in pools definable only by net-pay thickness or porosity changes (for example, Upper Devonian, Medina) rather than by clear-cut structural or stratigraphic boundaries. The data needed are good pressure and production data starting as early in the life of the pool as possible, geophysical ("mechanical") full hole logs giving good lithologic, water saturation, and porosity information, an analysis, if available, of water from the producing zone(s), good sets of well cuttings, and if possible core data from the pay section in at least one well in the area of interest. With this data, a pool can be defined in terms of reservoir volume or recoverable gas, instead of nebulous gross sand-thickness figures or sand-shale boundaries. The operator thus is in a better position to decide where to drill future wells, whether to drill that next well, and last but not least, to evaluate his property.

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Figure 1 Structure contours on top of the Onondaga Formation

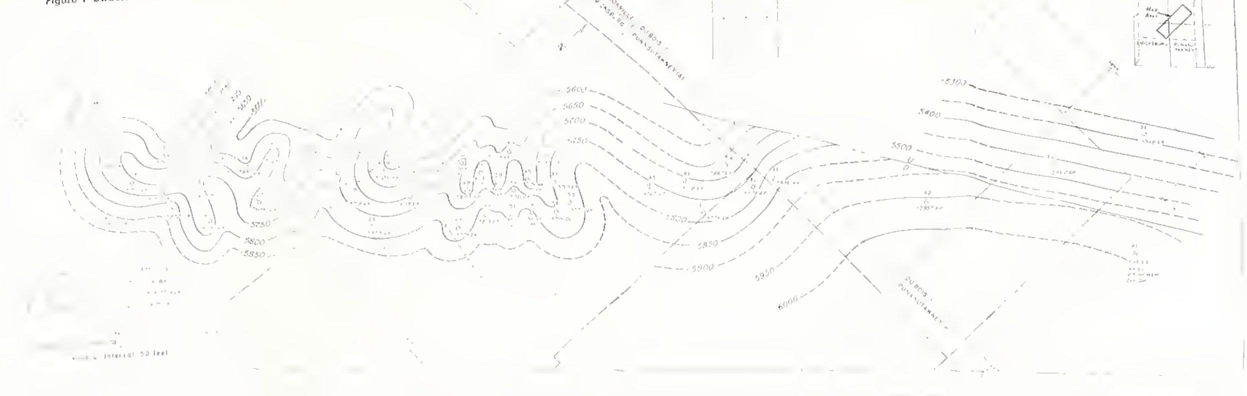

Figure 2 Structure contours on top of the Ridgeley Sandstone.

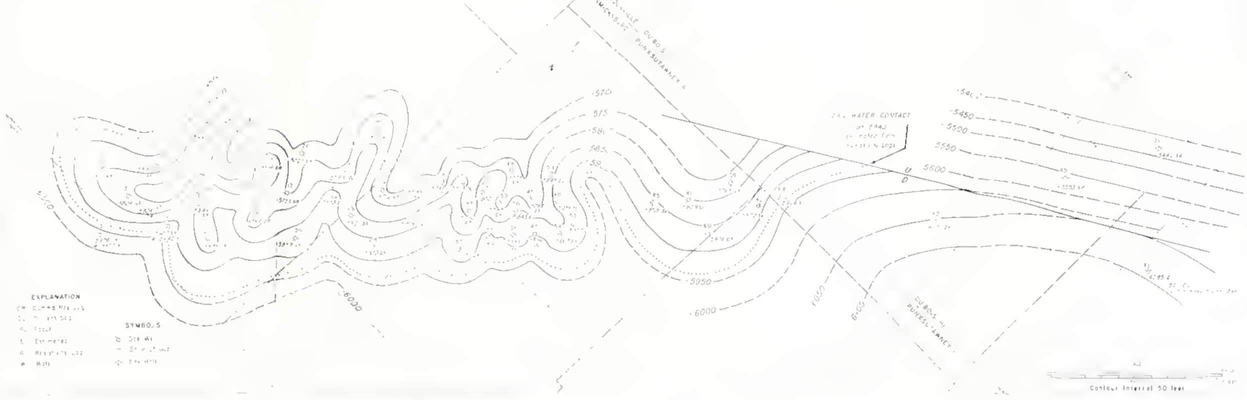

Figure 3 Structure contours on base of the Ridgeley Sandstone

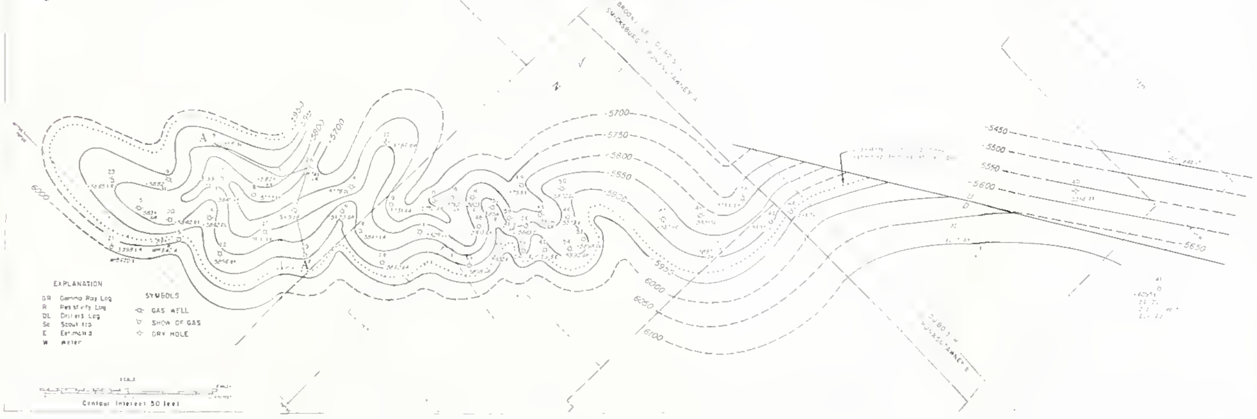

Figure 4 Isopach map of the Ridgeley Sandstone

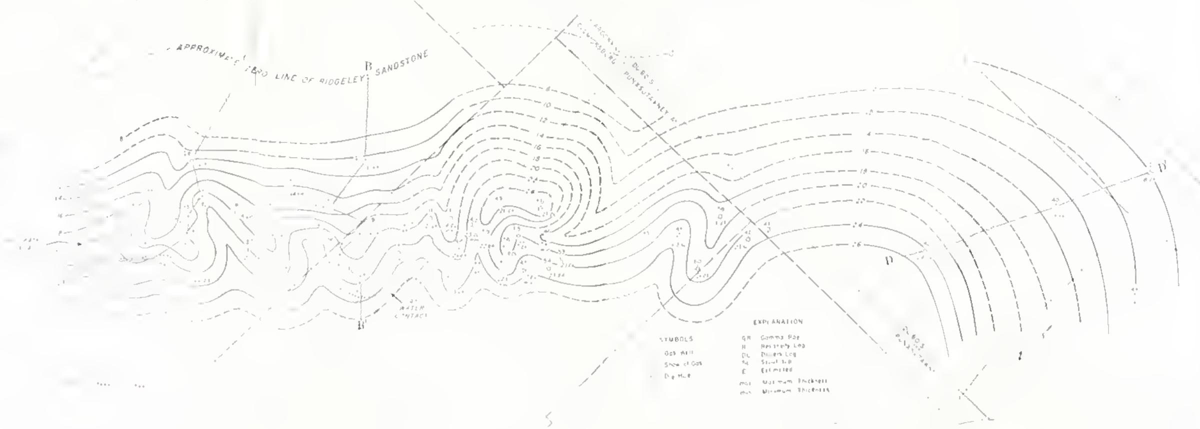

Figure 5 Net pay map: thickness of Ridgeley Sandstone with over 6 percent porosity

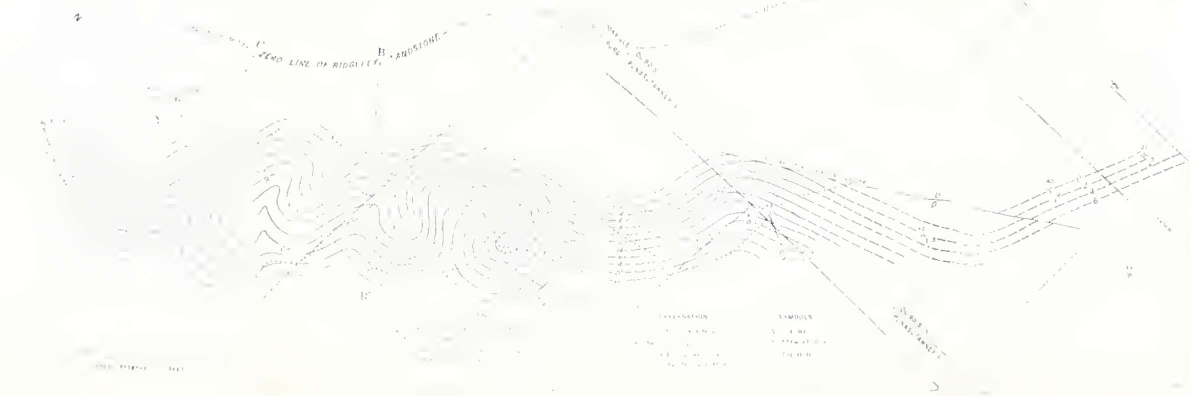

Plate 1 Elk Run gas pool maps

STRUCTURE SECTION A-A'

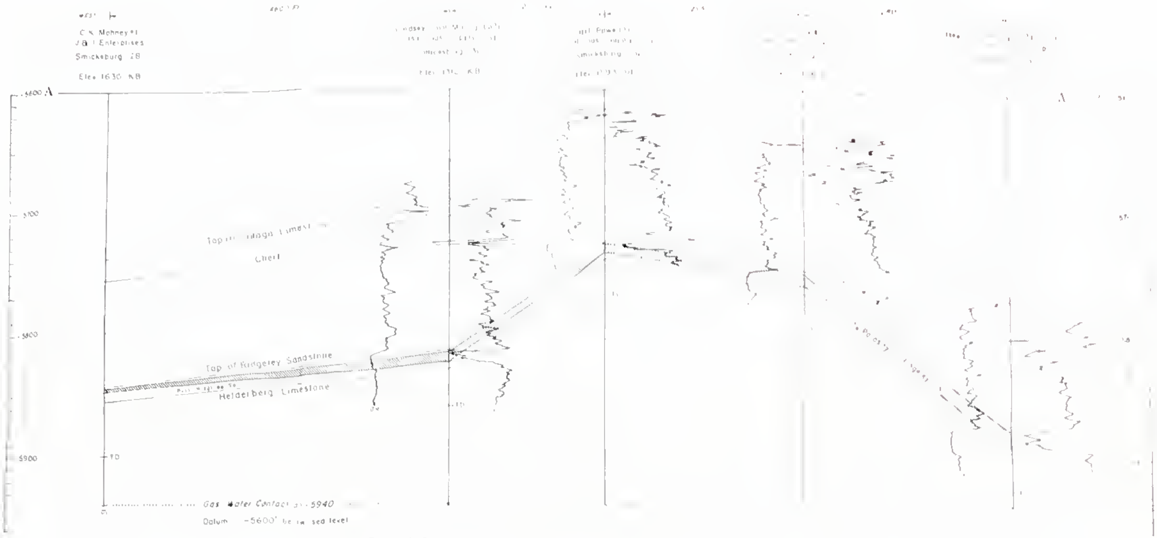

Figure 1 Structure section A-A' – section line shown in Figure 3 of Plate 1

STRATIGRAPHIC SECTION B-B'

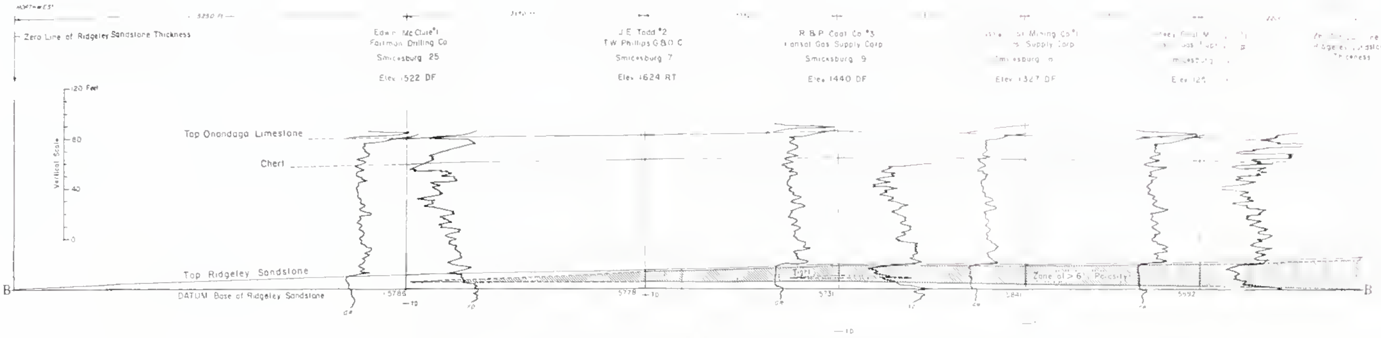

Figure 2 Stratigraphic section B-B' – section line shown in Figures 4 and 5 of Plate 1

STRATIGRAPHIC SECTION C-C'

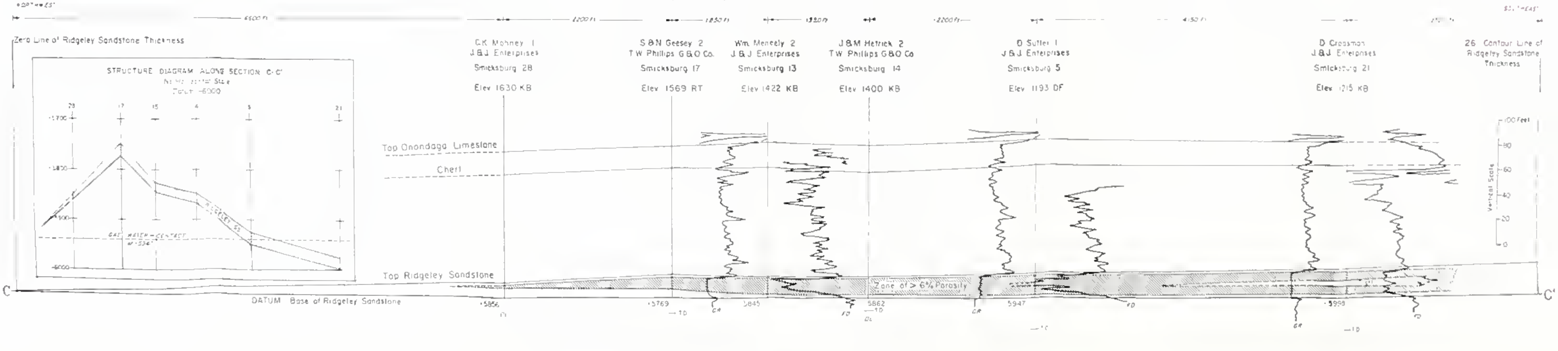

Figure 3 Stratigraphic section C-C' – section line shown in Figures 4 and 5 of Plate 1.

STRATIGRAPHIC SECTION D-D'

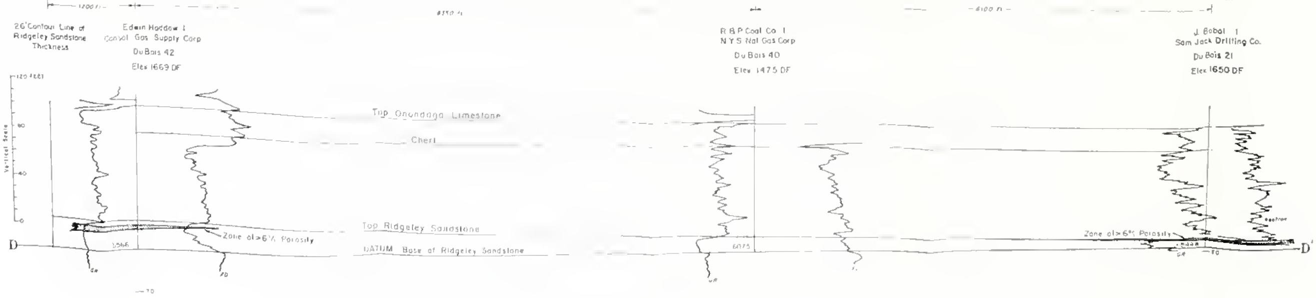

Figure 4 Stratigraphic section D-D' – section line shown in Figure 4 of Plate 1

Plate 2 Structure and stratigraphic sections in the Elk Run gas pool